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The
PROTECTION OF METALS
FROM OXIDATION AT HIGH TEMPERATURES

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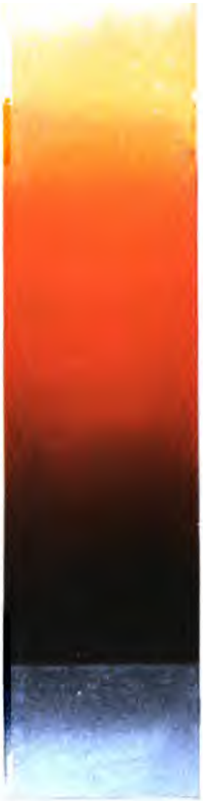
HEAT COLORS

NAME	COLOR SCALE	CENT.	FAHR.
11 White		1204°	2200°
10 Light Yellow		1079°	1975°
9 Lemon		996°	1825°
8 Orange		941°	1725°
7 Salmon		899°	1650°
6 Bright Red		843°	1550°
5 Cherry or Full Red		746°	1375°
4 Medium Cherry		677°	1250°
3 Dark Cherry		635°	1175°
2 Blood Red		566°	1050°
1 Faint Red		482°	900°

NOTE—The above is a graphic suggestion of the relation between heat colors and temperatures. Such a scheme can be *only approximately* correct.

PROTECTIVE COATINGS
FOR METALS

By

L.A.Hawkins and H.B.C.Allison

This brief review of some of the processes at present in use for protecting metals from oxidation will be confined to two types, firstly, that in which the metal itself is made more resistant, usually by some chemical treatment, and secondly, that in which another metal is used as a surface coating.

In the first instance a coating is formed which must possess the following properties, if it is to be successful: It must be homogeneous, continuous, resistant to attack by acids or alkali, firmly attached to the base metal and must have a similar expansion coefficient. The ideal metal coating should also be homogeneous and continuous, but should be strongly electropositive to the base metal and should form electropositive alloys with it, so that in case of oxidization the coating will be attacked and the base metal protected.

As iron is the metal most commonly used as the base, the processes chosen will be those used for its protection, although some may be applicable to other metals.

Protection by Oxide Coatings:

It was known for a considerable time before any process was devised that the black or magnetic oxide formed on iron, under certain conditions was a very fair protective coating. Attempts to control and improve this coating have led to a number of patented processes of which the following may be taken as typical.

Bower-Barff Process:

The pieces to be treated are heated to a temperature of 900 deg. C. in a closed retort. When this temperature has been reached, super-heated steam is admitted for twenty minutes and a coating consisting of a mixture of red and black oxides is formed. Producer gas is then substituted for the steam and allowed to act for the same length of time. After cooling somewhat, the pieces are oiled and a smooth, green-black coating is produced, which affords efficient protection from sea water, acid fumes, etc., and will stand a wide variation in temperature.

Gesner Process:

This is a further development of the above process. The pieces to be treated are heated to a temperature of 900 deg. C in a closed retort; when this temperature has been reached, super-heated steam is admitted for twenty minutes after which steam at low pressure is let in at intervals for 30 minutes. The steam, on entering, passes through a red-hot pipe at the base of the retort, and is thus partially decomposed into hydrogen and oxygen. After this treatment, a small quantity of naphtha or hydrocarbon oil is introduced and allowed to act for fifteen minutes to reduce any red oxide, and also to carbonize the surface. The coating is said to be a compound of iron, hydrogen and carbon, and analysis has shown that a minimum of two per cent hydrogen is present. It is an improvement on the Bower-Barff process in that the danger of warping during the process is removed, since the treatment is carried out at lower temperature, and the tendency to scale is reduced for the same reason. Both processes are quite expensive.

Protection by Chemical Means:

There is one process which may be of interest in this connection, known after its inventor as "Coslettizing."

The pieces to be coated are first cleaned as usual, either by pickling or sand blasting, are then placed in a boiling water solution of phosphoric acid, in which iron or zinc filings are always present. The period of treatment is from one-half to three hours, depending on the thickness of the coating desired. After drying, the pieces are usually oiled. By this treatment a very slight amount of the surface of the article is converted into certain phosphates of iron, but most of the coating comes from the solution itself. This coating has been found to be particularly useful in the tropics, and is used in one instance for typewriters. It is, however, subject to patent restrictions.

Protection by Another Metal:

The agent used in the majority of cases for protecting iron is the metal zinc. Zinc is strongly electropositive to iron and so are its alloys, if free from impurities. It is also readily available and may be applied by a number of processes.

Hot Galvanizing:

The oldest process is that of hot galvanizing, which consists simply of cleaning the pieces, coating with a suitable flux and then dipping in the molten zinc. The piece is usually wiped after this to improve the coating. This process has the disadvantage of limiting the thick corrosive substances in the coating, which may cause early failure.

Cold Galvanizing:

Another process which is being used more and more as it is improved is that of wet galvanizing or electroplating. In this case the article to be coated is suspended as a cathode in a suitable bath and is subject to easy control. It provides a coating of high purity and uniform thickness in general, but recesses and corners cause some trouble. It is liable to be more or less porous and may contain acid which will eventually cause failure. In both of these processes, hot or cold, the coating does not become intimately connected with the base metal through deep alloying.

Lohman Process:

A modification of this process is known as the Lohman Process. After cleaning, the article to be coated is dipped in the Lohman Bath, which is a solution of hydrochloric acid, mercuric chloride and ammonium chloride: it is then dried before immersing in the molten metal, which may be any one or a mixture of a number of metals such as lead, zinc and tin. The chief point in its favor seems to be that the junction between the iron and the protective alloy is kept free from all oxide, and, therefore, the alloy will fill all the pores and no corroding agent can be included.

It is claimed by its backers that a graduated alloy is formed so that the protective coating cannot be completely broken through except by breaking the sheet itself.

Sherardizing:

The latest process of this type is sherardizing. The object to be sherardized is placed in an iron drum which is filled with a mixture of finely powdered zinc and zinc oxide, in varying proportions, and is heated in a reducing or inert atmosphere for a period of time, the length of which depends on the thickness of coating desired. The coating so obtained consists of four protective layers. Next to the pure iron is an alloy "C", rich in iron, upon which is another definite alloy "B", containing more zinc. Then there is a layer containing a number of more or less unknown alloys, and finely a layer of pure zinc. This makes a coating which is not easily broken down and which is continuous. The principal objections to its use are the high temperature to which the piece must be subjected and the increase in size which may be caused.

The theory which has been advanced to explain this process is interesting in that it may be considered as a distillation process. The zinc dust which is obtained from the zinc smelters is said to be in a state of unstable equilibrium, so that in contact with the hot iron it undergoes a change tending to restore it to the normal condition. During this change some of it alloys with the iron, thereby lowering the vapor pressure for zinc in that region. A slow distillation then begins from the zinc nearest the object itself. As the alloy becomes richer in zinc the difference in vapor pressure becomes less and less and then finally becomes zero. This is found to be the case in practice. The deposition becomes slower as the time is extended.

Schoop Process:

One of the recent processes is the Schoop Process. This is applicable to the deposition of metals or alloys on any sort of an object. The apparatus consists of a pistol into which the coating metal is fed as a wire. It passes through a straightening and centering device into the nozzles where it is fed through a burner whose temperature may be regulated from 700 deg. to 2000 deg. F. The molten metal is carried a short distance by the gas current and is suddenly caught by a powerful blast of compressed air which shoots it out of the nozzle with a velocity of 3000 feet per second, directly on the object to be coated, which is held a short distance away. The coating is continuous, and of any desired depth and is also exceedingly intimate. In the majority of cases it must be applied by hand.

Calorizing:

This recently developed process makes use of aluminum as the protective metal and is of particular advantage in preventing oxidation at high temperatures. The protective action is due to the oxide formed by the action of heat on the protecting metal, rather than to any electrolytic relations between the aluminum and the base. The product is distinguished from that of the foregoing processes in that they are intended primarily to give protection against oxidation at ordinary temperatures, or corrosion, as it is frequently called, while the calorizing process is intended primarily to protect against oxidation at high temperatures.

It has been found very useful in the case of iron utensils subject to direct contact with flames at temperatures to nearly 1100 deg. C., and also in the case of boiler tubes, for the life is increased many times by this treatment and the saving in the cost of replacements is much greater than the additional initial cost of calorizing.

Copper parts also, which are exposed to high temperatures, can have their life increased by calorizing. In some cases calorized copper may be used advantageously in place of aluminum bronze. There are of course many homogeneous alloys, some of which, such as bronze, are highly resistant to corrosion or oxidation at ordinary temperatures, and others such as ferro chrome nickel alloys, which are highly resistant to oxidation at high temperature, but the products of the process above described differ from such alloys in that they consist of a relatively inexpensive metal, such as iron or steel, in itself readily oxidizable, but covered by a continuous protective coating.

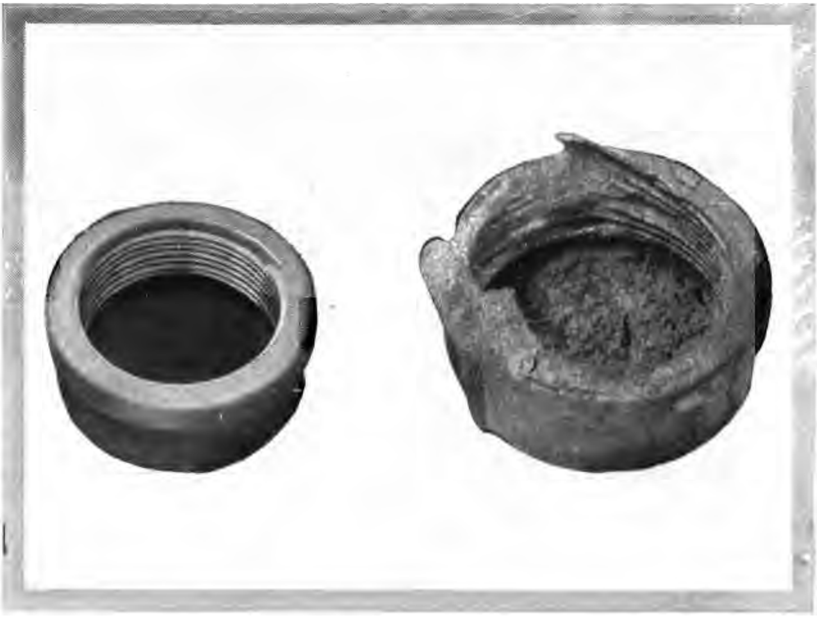
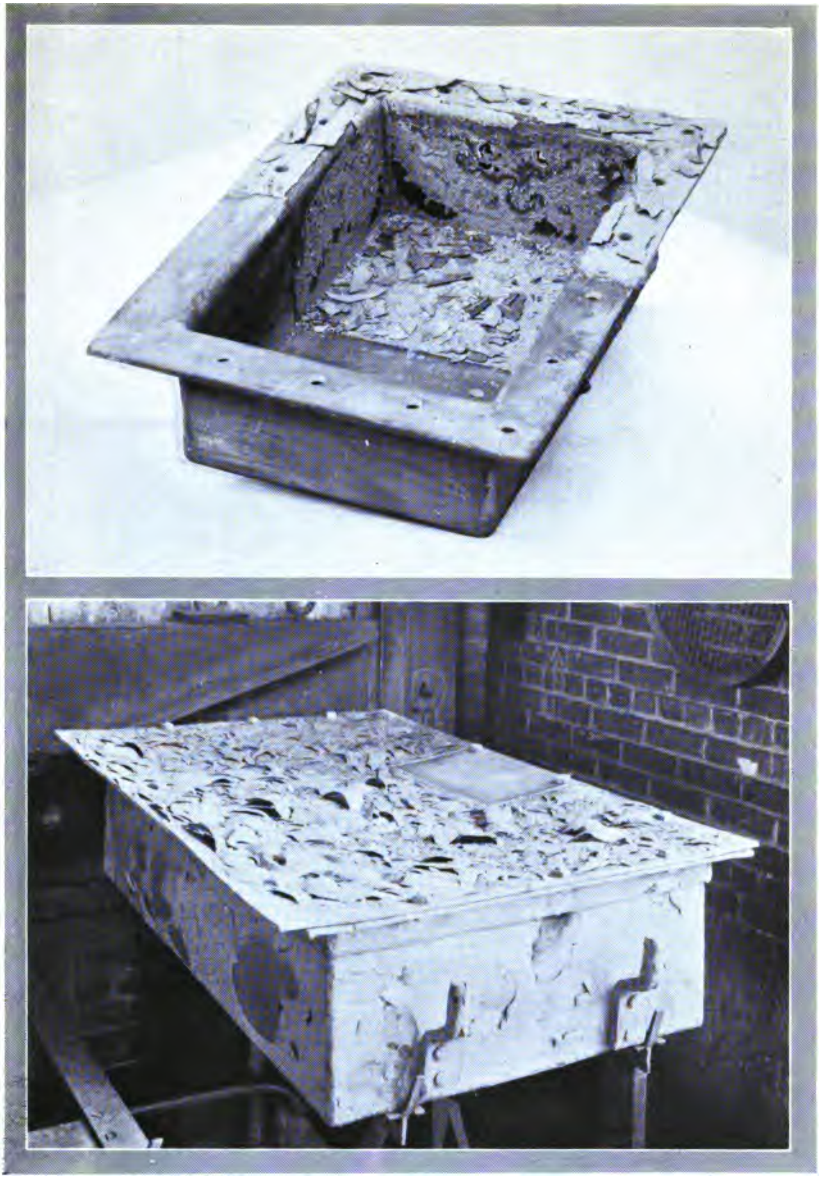


Fig. 1—Two standard wrought iron pipe caps, left calorized, right uncalorized. They were tested for same period of time under identical conditions



Figs. 2 & 3.—(Upper) Annealing box which was first cut in two, one-half was then calorized and it was then welded together. It was then tested; (Lower) Small portion was cut from cover of this annealing box, calorized and welded back. It was then tested. The result of the test is clearly shown

CALORIZING

ITS DEVELOPMENT and APPLICATION

Calorizing, the only successful and economical process rendering iron, steel, copper, nickel, brass, or other metals highly resistant to high temperatures, is now commercially available. It fills a tremendous need. There is a vast future before it in many fields:—in thousands of possible diversified applications.

Since the close of the bronze age, iron has been used for ovens, utensils, and tools of every description for all temperatures up to dull red, but for higher temperatures there has been even up to the present day, no moderately priced metal available. Platinum, because of its cost, has been quite limited in use. Copper and most of the alloys, such as brasses and bronzes, will not withstand repeated heating in the air to red heat without scaling badly. Nickel and cobalt are the most stable of the more common metals which may be worked or cast and are fairly cheap, and will withstand moderately high temperatures. Some of the alloys containing nickel or chromium are also quite permanent in the air at red heat, but all of these at the best are either too costly to be generally used in a commercial way, or they are only available as heavy castings as they are not easily wrought.

Seeking to find a method of protecting their electric heating elements, the General Electric Company spent years in research work, having at their command the finest research laboratories in the world. After extensive investigations the Calorizing Process was discovered and has been in use since 1911. It consists of heating metals in stationary or rotary retorts in a reducing atmosphere, with a mixture containing finely divided aluminum. This treatment, conducted at high temperature, so thoroughly infuses aluminum into the exposed portion of the metal being treated, as to form a homogeneous aluminum alloy for a certain depth. This depth ranges from a few thousandths of an inch to the permeation of the entire mass, varying with the duration of the treatment.

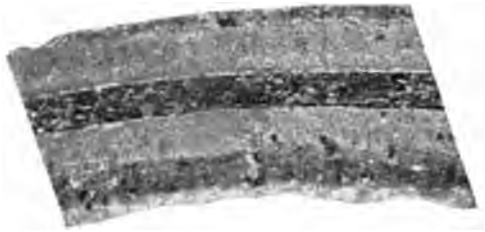


Fig. 4.—Micro-photograph showing cross-section of calorized steel tubing

Cut number 4 a micro-photograph of a cross-section of calorized tube, clearly shows the diffusion of the aluminum into the base metal. The extreme outer portion is alumina; under this is a wide band of ferro-aluminum: rich in aluminum in the center the steel remains unchanged, except that it is thoroughly annealed. Figure 5 shows cross-section views of a number of copper rods 1¼ inch in diameter, which were calorized for about two hours. The depth of the alloy is sharply defined.

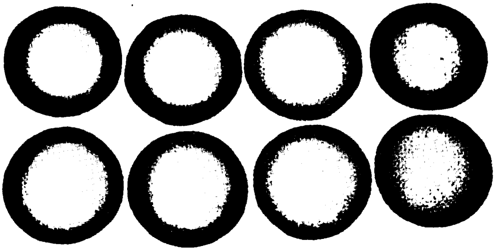


Fig. 5.—Cross-section of calorized copper rods showing depth of alloy

The essential point in difference between the effects of calorizing and any process hitherto used commercially, such as galvanizing, plating or coating, is that the protective metal is not imposed as coating or skin upon the metal to be treated, but on the contrary, enters into intimate association with it, forming a "solid solution" alloy. For this reason, should the outer surface become injured the protective surface renews itself. Calorizing is not intended to protect against rusting or corrosion as is sherardizing for example, but is primarily a protection against burning or scaling. Calorized copper, brass or nickel however are also excellent non-corrosive elements and are strongly resistant to the acids. The very successful use of calorized copper as condenser tubes is dealt with later.

The dimensions and weight of the metal treated are very slightly increased by calorizing. The increase in dimensions is usually not over a few thousandths of an inch.

Authentic Tests of Calorizing:

As evidence of the performance of calorized metal under test conditions, the pipes, both from the same piece, shown in Fig. 8 were photographed. The longer one only was calorized after which treatment it was heated to 1800 deg. F. in an electric furnace open to the air and cooled. This operation was repeated several times. The total time during which the maximum temperature was maintained was about fifty hours. Next it was heated to 1620 deg. F. and plunged into cold water after it had cooled to a dull red. This was repeated three times and the surface showed no signs of cracks or scale. Finally this piece and the untreated one were heated side by side with an ordinary laboratory blast lamp to a temperature of about 1700 deg. F. for four hours, then cooled and the heat once more applied for four hours. At the end of that time the untreated pipe was badly burned, the point where the flame was applied directly having been reduced to one-half of the original thickness, while the whole surface was blistered. The contrast between this pipe and that which was calorized was very marked, for even upon close examination, the latter appeared to be unchanged.

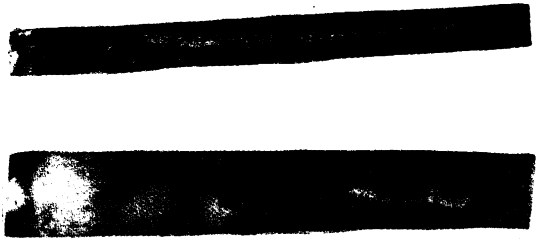


Fig. 6.—Calorized and uncalorized tubes after test in nitrogen purification plant

The cut on page 7 shows a similar comparison between two sections of steel tubing, one calorized and the other not, which were both subjected to a temperature of 1472 deg. F. in a gas furnace for 100 hours. The uncalorized pipe was practically destroyed, while the calorized pipe was unharmed.

Photographs of tubes under working conditions are shown in Fig. 6. These tubes were part of a small nitrogen purification plant; both were heated by gas in a brick furnace, the large tube to a temperature of approximately 1500 deg. F. and the smaller one to about 1170 deg. F. The larger tube was calorized, and had been in use for over 400 hours with no observable deterioration, whereas, the smaller tube was badly burned at the end of the same run. After the tubes had run 650 hours they were photographed. This time the calorized tube showed positively no evidence of scale, though the other was burned completely through and this despite the fact that it had been subjected to a temperature of 270 deg. F. lower than that applied to the first tube.

The results of a sulphur dioxide test is shown in Fig. 9. Two pieces of extra heavy wrought pipe, one calorized, the other uncalorized, were run side by side in a furnace at 1500 deg. F. in an atmosphere of sulphur dioxide for a period of four hours. At the end of this time the ordinary pipe was badly burned and the experiment was discontinued. The calorized pipe was in as good condition as before the test.

Tests of Retorts and Carbonizing and Annealing Boxes:

Fig. 7 is the photograph of calorized and uncalorized retorts, subjected to identical temperatures; the calorized retort for 150 hours and the uncalorized retort for 50 hours. It will be noted at once that the uncalorized retort is scaled very badly. To further

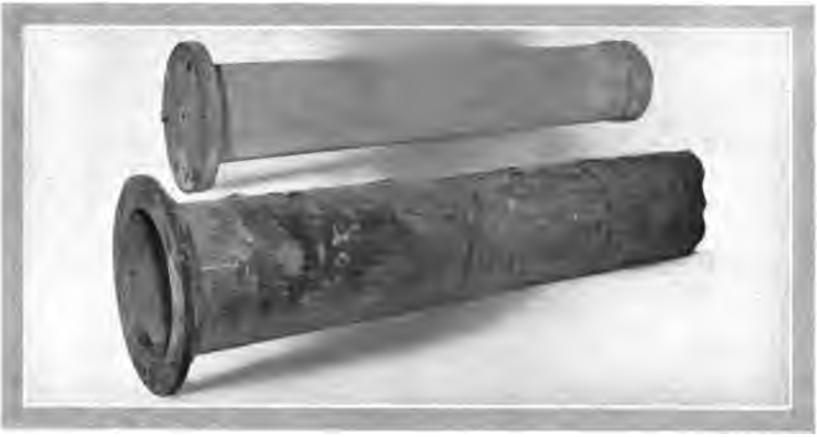


Fig. 7.—Two retorts, the upper calorized, the lower uncalorized, after being subjected to test

bring out the contrast in the relative durability of two annealing boxes, two photographs are shown on the frontispiece of this article on page 6.

The box in Fig. 2 at the top of page 6 was first cut in two, then one half was calorized and the two portions welded together again. The illustration clearly shows how the plain iron scaled when exposed to a temperature of 1800 deg. F. for 40 hours. Fig. 3 on the same page shows an annealing box constructed of plain sheet iron throughout, with the exception of a small rectangular piece, which was first cut from the cover, heat treated by the calorizing process, then welded into the cover. At the time the photograph was taken, the box had been placed in the annealing oven for two periods of five hours each at 1800 deg. F.

Physical Tests

While some of the foregoing experiments were under way, the National Tube Company became interested in Calorizing, and early in 1919 subjected it to a series of tests. Their statement is as follows: "Our Laboratory reports that the calorized portion on 4" boiler tubes which they tested, did not fail when the samples were subjected to the standard boiler tubes flanging, crushing, flattening, expanding, and ring tests. These standard tests are shown in Fig. 5 of the attached bulletin."

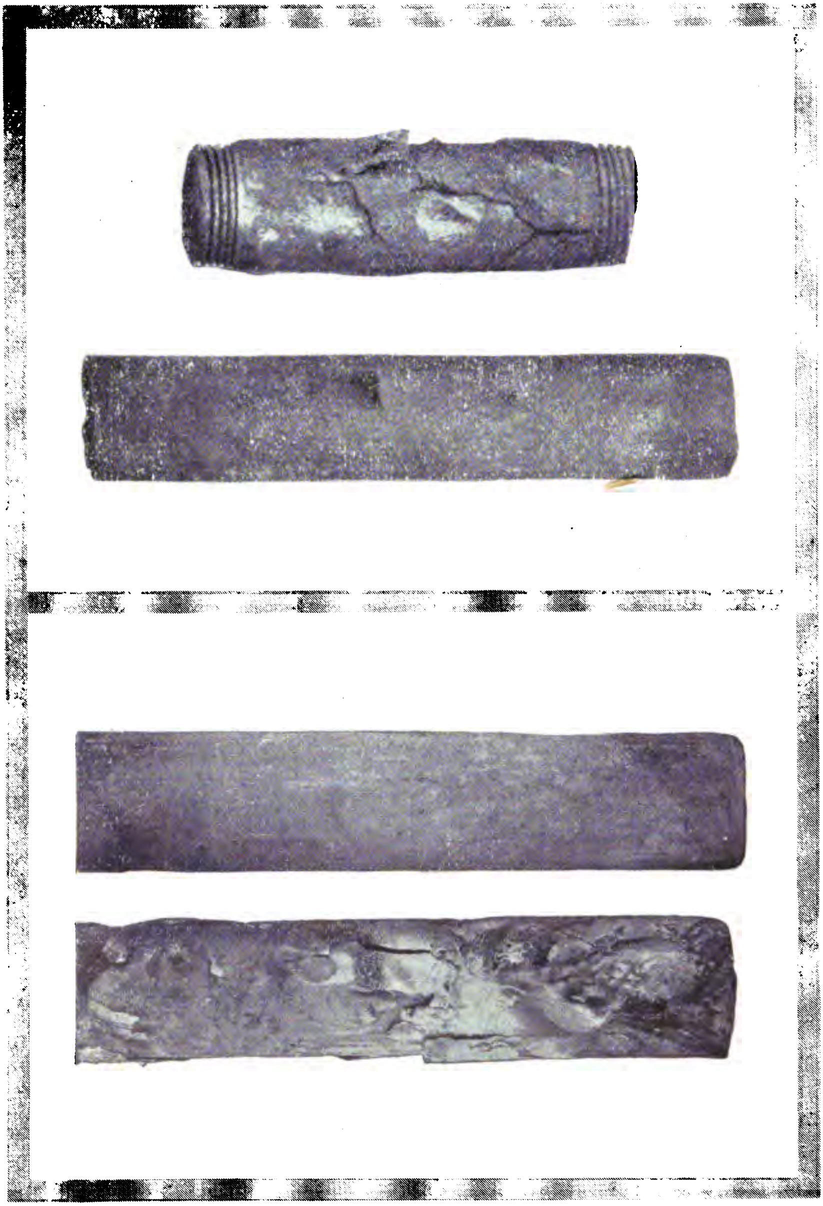
The following are the physical tests on Calorized Steel Tubing:

Test No.	Elastic Limit Lbs. per Sq. In.	Ult. Strength Lbs. Sq. In.	% Elong. 2 In.	% Elong. 8 In.	% Reduction
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*Rough Break—pulled out.
• [illegible]

From this it would appear that the calorizing process anneals the material, giving results which compare very favorably with those obtained by a soft annealed finish.

Fig. 5 referred to is here reproduced as Fig. 11 of this article. The conclusion to be drawn from these investigations is: Calorizing does not injure the metal which has been treated. Also that calorized material is capable of withstanding all ordinary handling without deterioration of the alloy or calorized portion. It should be understood, however, that calorized metal cannot be hammered or



Figs. 8 & 9.—(Upper) Two pieces of wrought iron pipe, the longer calorized, the shorter uncalorized, both tested at 1800 deg. F. for the same period of time; (Lower) Two pieces of extra heavy wrought iron pipe, the upper calorized, the lower uncalorized, after subjection to the sulphur dioxide test

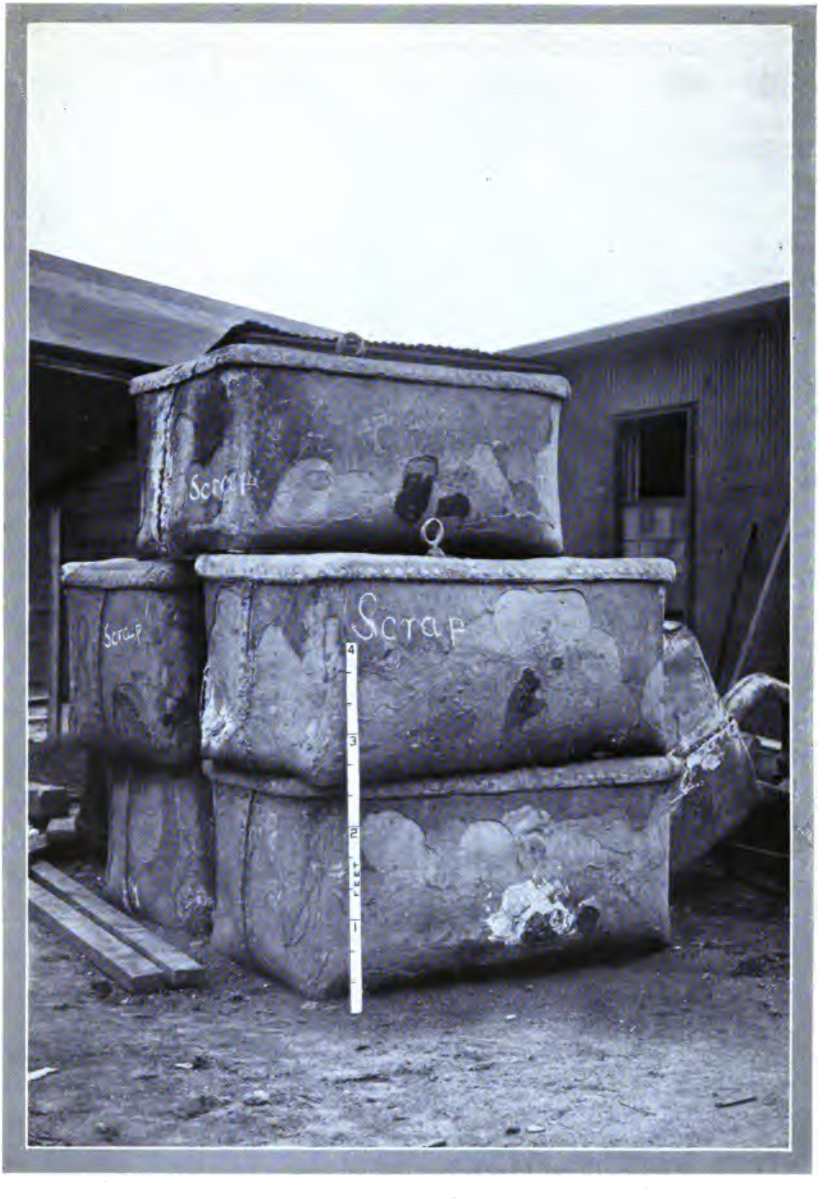


Fig. 10—Nest of annealing boxes burned to a crisp and condemned as scrap. Calorizing would prevent it

bent cold, but at a bright red heat can be bent without affecting its resistance to oxidation.

Although these tests show that the mechanical properties of the steel are not injured by calorizing, it must be pointed out that the rich aluminum alloy which forms the protective coating is very hard; any bending or mechanical working should be done as far as possible before calorizing. If it must be done afterwards the piece should be first heated to redness. Above this temperature the calorized coating is readily worked without injury.

The General Electric Company writes: "Calorized iron will withstand temperatures of 1800 deg. F., whereas, untreated metal begins to oxidize noticeably at 1100 deg. F. and at 1800 deg. F. its disintegration is extremely rapid. Many gases contain sulphur dioxide and carbon monoxide which have an extremely deleterious effect on ordinary metal, while our tests have shown that calorized metal is not affected by these gases, in the percentages in which they occur in furnace gases."

Calorized Copper:

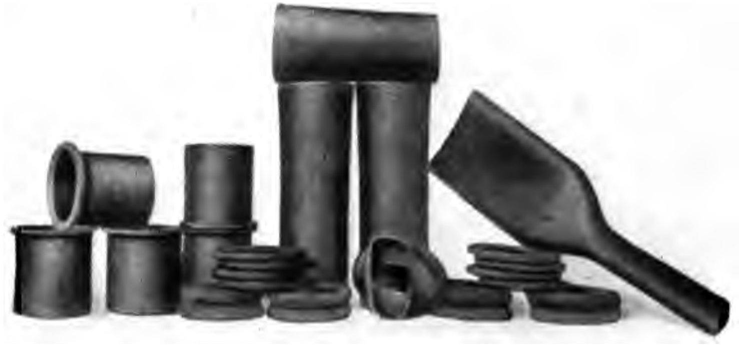
Copper parts also, which are exposed to high temperatures can have their life increased by calorizing. In some cases calorized copper may be used advantageously in place of aluminum bronze. For instance, a large power station had trouble from early corrosion of its condenser tubes. These tubes were copper and were supposed to last at least a year. As a matter of fact while occasionally tubes would last as long as six years, other tubes would fail in four or six weeks after they were installed. About two-and-a-half years ago calorized tubes were installed and so far not a tube has failed. The life of copper contacts can be increased by calorizing. For instance, a set of railway controller contacts which were calorized showed several times the life of the ordinary untreated contacts.

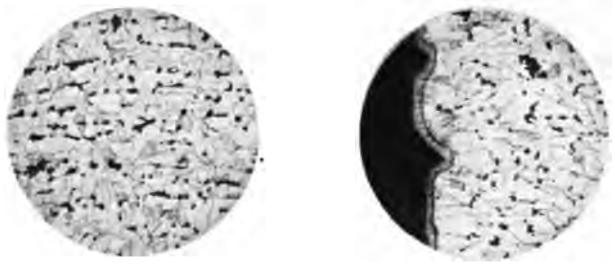
Reports By Well Known Companies:

The marked superiority of calorized metal over iron and steel for unusual heat conditions has commended itself to a large number of well known companies. Extracts from their signed statements follow:

The Dayton Company, Buffalo, N. Y.

"Calorizing certainly prevents oxidization, increases heat conductivity and raises the melting points. We find it very essential in the treating of our gas-making retorts, which are subjected to an oxidizing atmosphere at 1600 to 2000 deg. F."





Figs. 11 & 12.—(Upper) The National Tube Co.'s standard tests as applied to calorized tubing; (Lower) Micro-photograph showing structure and cross-section of calorized tube after crushing test. The homogeneity of the alloy is clearly shown

Westinghouse Lamp Company, Bloomfield, N. J.

"These calorized tubes are used in furnaces where the temperature is in the neighborhood of 900 to 1000 deg. C. At this temperature, we get normally double to triple the life which we would obtain from ordinary wrought iron tubes."

The Denver Rock Drill Manufacturing Co., Denver, Colo.

"By submitting the pipe (calorized pipe used as containers in their steel carbonizing process) to temperatures of 1650 to 1700 deg. F. together with wrought iron, which we ordinarily use of the same shape, size and thickness, the calorized material lasted very nearly ten times as long as the plain pipe."

The Bristol Company, Waterbury, Conn.

"A great many of our customers who have used pipe so treated (calorized) have reported very favorably as regards increase of life of Pyrometer Protection Tubes, in most cases three to five times as long as the ordinary wrought iron or steel pipes."

International Acheson Graphite Company, Niagara Falls, N. Y.

"We find that the tubes so treated (calorized) will give four times the length of service under the same conditions, as will tubes from extra heavy seamless tubing."

The Rowe Company, Plantsville, Conn.

"For your information, we would advise that the regular retorts have an average life of 100 hours, and up to date the Calorized retort has been in process something over 400 hours."

International Coal Products Company, New York City.

"You will note that we really are getting excellent results from all the retorts which you manufactured for us, and that there is no comparison between the calorized and uncalorized tubes."

Standard Oil Company, San Francisco, Cal.

"These samples were subjected to 900 deg. C. for ten days and then examined. The uncalorized piece had gone entirely to pieces. The calorized piece was in good condition. This piece was then returned to test for another forty days, at the end of which time it was in perfect condition. Once again it was returned to test, in the temperature mentioned above, for two months and then examined; it was still in perfect condition."

Oklahoma Bottle & Glass Company.

"We have used calorized metal as a substitute for a clay part in connection with hot molten glass. The calorized metal does not throw off streaks of rust as does the ordinary untreated iron. We find that it is very economical when compared with the large number of clay parts we were compelled to use for the same work."

Calorizing has been put to a great variety of uses including its application to retorts, carbonizing and annealing boxes, pyrometer tubes, furnace castings, tubes for preheating air, flue lining, pipe for conveying molten glass, torch nozzles, blast furnace tuyeres, oil crackers, soot blower units, lead pots, valve and piston heads for Diesel Engines, preheating coils for oil burners, hot bulbs for oil engines, etc.

Carbonizing and annealing boxes and a variety of heat treating equipment of this nature has been successfully calorized. The calorization prolonging its life from three to thirty times.

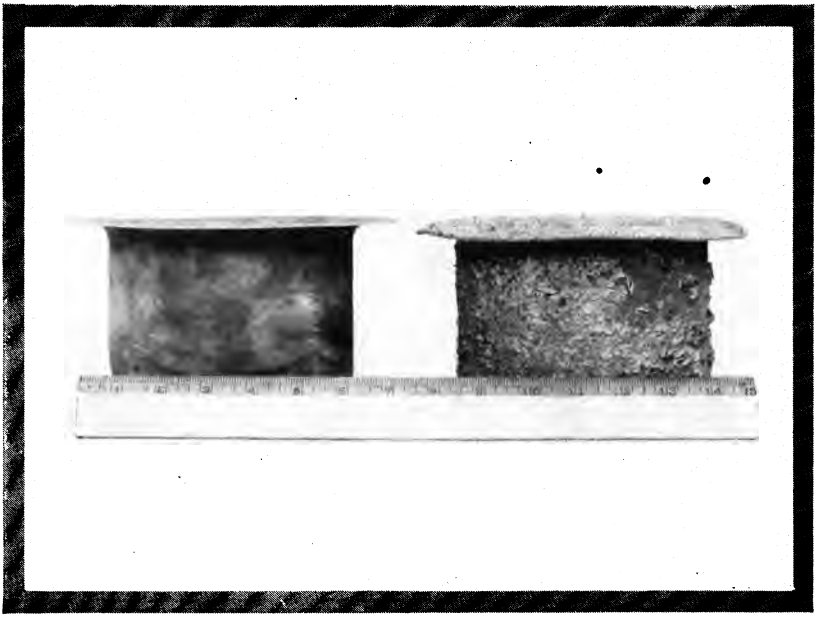


Fig. 13.—Effect of 800° C in oil furnace for 100 hours on calorized and uncalorized sheet iron shells

Calorized Pipe and Tubes for Heat Treatment Processes and for Boilers and Condensers:

Pipe coils which have first been welded then calorized are shown in Fig. 14. These particular coils are used for preheating air and producer gas for forge furnaces. Calorized boiler tubes can be successfully expanded after calorizing, as shown in Fig. 15.

It is entirely feasible to make up calorized coils of pipe and a wide variety of shapes, lengths, and sizes. Straight pipe ⅛″ to 18″ diameter has been calorized in lengths up to 20 feet. There is no limit to the size of material which may be treated. Calorized pipe which comes under the class of retorts is shown in Figs. 18 and 19.

Calorized steel is particularly adapted to Pyrometer Protection Tubes because of the high temperature to which they are exposed. Not only is it cheaper than any of the chrome steel alloys which have at times been offered for this purpose, but it possesses other advantages as follows:

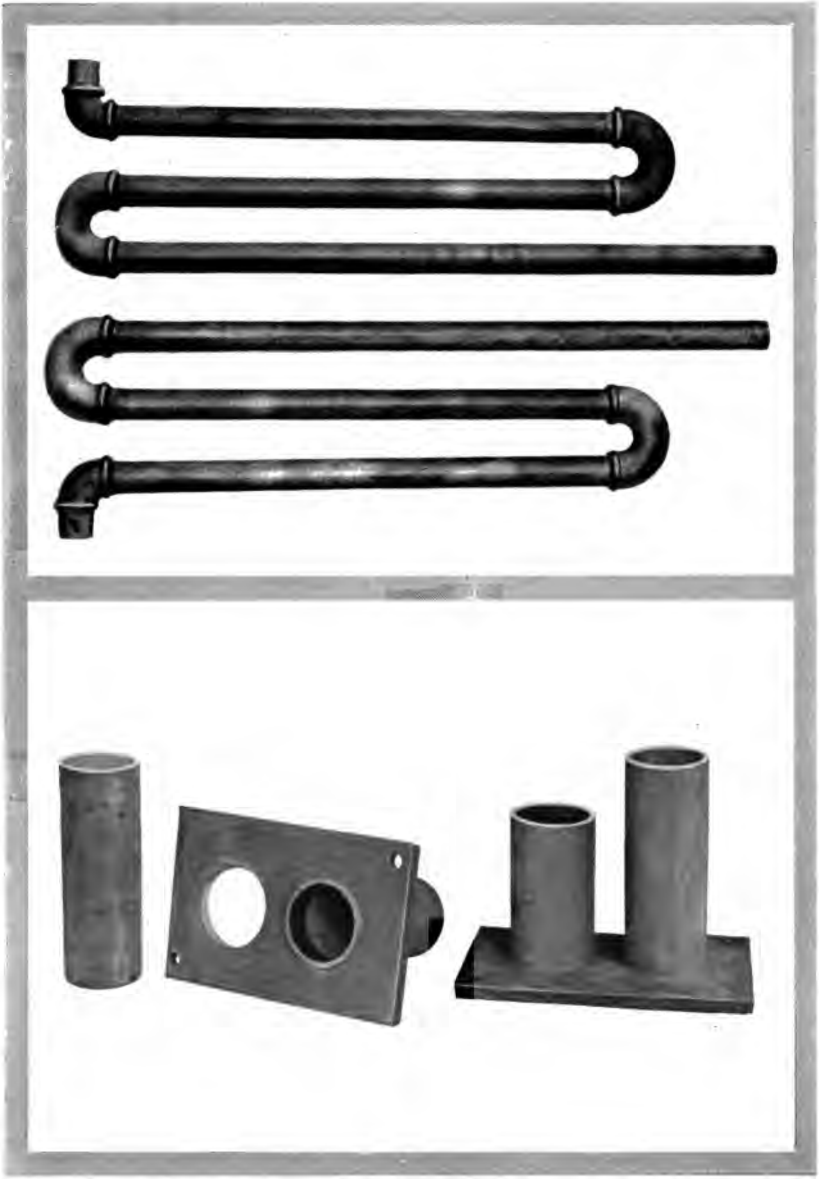
1. Greater uniformity of structure of material due to natural superiority of a calorized wrought steel tube over a cast tube.
2. Non-porosity.
3. Decrease in the "lag" on pyrometer readings.
4. Special shapes can be bent from standard tubing either before or after calorizing, eliminating the expense of special castings.

Among prominent pyrometer manufacturers who have adopted calorized pyrometer protection tubes for use with their pyrometers may be mentioned:

The Bristol Company
The Brown Instrument Co.
The Thwing Instrument Co.
Taylor Instrument Co.
Wilson-Mæulen Co.
Charles Englehard.

Others are being added to this list from time to time.

A stock of calorized pyrometer tubes, also a few special shapes, are shown in Figs. 16 and 17.



Figs. 14 & 15.—(Upper) Superheater coils welded and calorized; (Lower) Calorized boiler tubes expanded into header

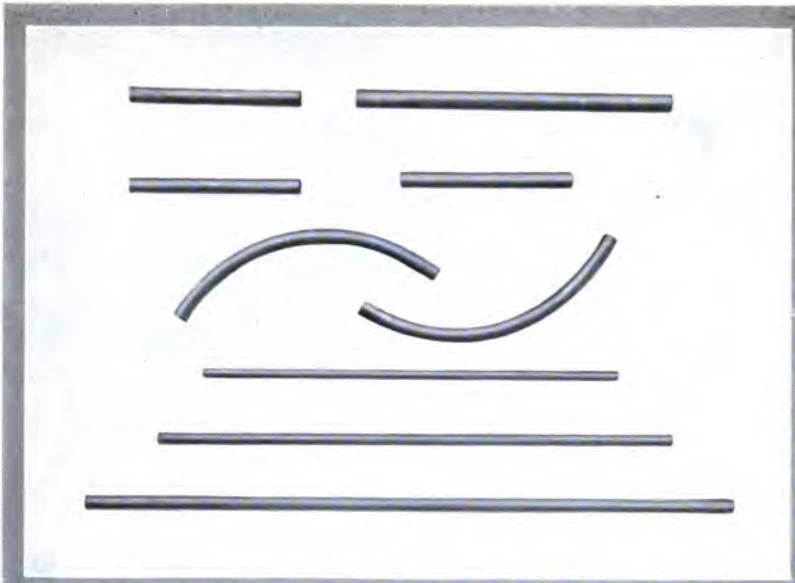


Fig. 16.—Calorized pyrometer tubes
Fig. 17.—A thousand tubes awaiting call

Calorized Metal as Applied to Soot Blowers:

Soot blowers as applied to boilers must be exposed continuously to furnace gases at high temperatures, and are not cooled by water or steam as are boiler tubes. Ordinary iron or steel will not give successful service. Under these conditions one of the early means employed in protecting this equipment against burning out consisted of two extra heavy steel pipes, placed one within the other, the space between being filled with insulating material of special composition. This type of installation was fairly successful, but involved an excessive first cost; therefore, manufacturers of soot blowers were constantly on the lookout for material from which these units could be economically made, and which would give even more satisfactory results. As a dominant factor in the mechanical soot blower field the Diamond Power Specialty Company was first to develop a means of protecting these units.

Soon after the calorizing process was announced, the Diamond Power Engineers made an extensive investigation of this new process for protection from oxidation. In addition to mechanical tests, trial installations were made in all the different types of water tube boilers. In making tests, calorized soot blower units were placed in the hottest passes where the temperatures ranged from 1800 to 2500° F. The need of blowers at these locations had long been recognized, but their application had been considered impracticable. Performance of the calorized units was watched with keen interest for months. In the end they proved that they fully met the hardest service conditions. There were no signs of scaling or disintegration from the long exposure to high temperatures. Thousands of successful installations have been made, and are now giving satisfaction in all types of water tube boilers.

Among many prominent users of soot blowers constructed of calorized metal may be mentioned:

- **Babcock & Wilcox Co.**
- **Detroit Edison Co.**
- **Edison Electric Illuminating Co. of Brooklyn**
- **American Railways Co.**
- **DuPont Powder Co.**
- **Illinois Steel Co.**
- **Carnegie Steel Co.**
- **International Harvester Co.**
- **Calumet & Hecla Mining Co.**
- **Miller Rubber Co.**
- **U. S. Steel Corporation**
- **American Can Co.**
- **Lima Locomotive Corporation**
- **General Electric Company**
- **Scovill Manufacturing Co.**
- **Ford Motor Co.**
- **Bethlehem Steel Co.**
- **American Sugar Refining Co.**
- **Standard Oil Co.**
- **Inland Steel Co.**
- **New York Central Rys. Co.**
- **Solvay Process Co.**
- **Pressed Steel Car Co.**
- **American Smelting & Refining Co.**
- **Pierce Arrow Co.**

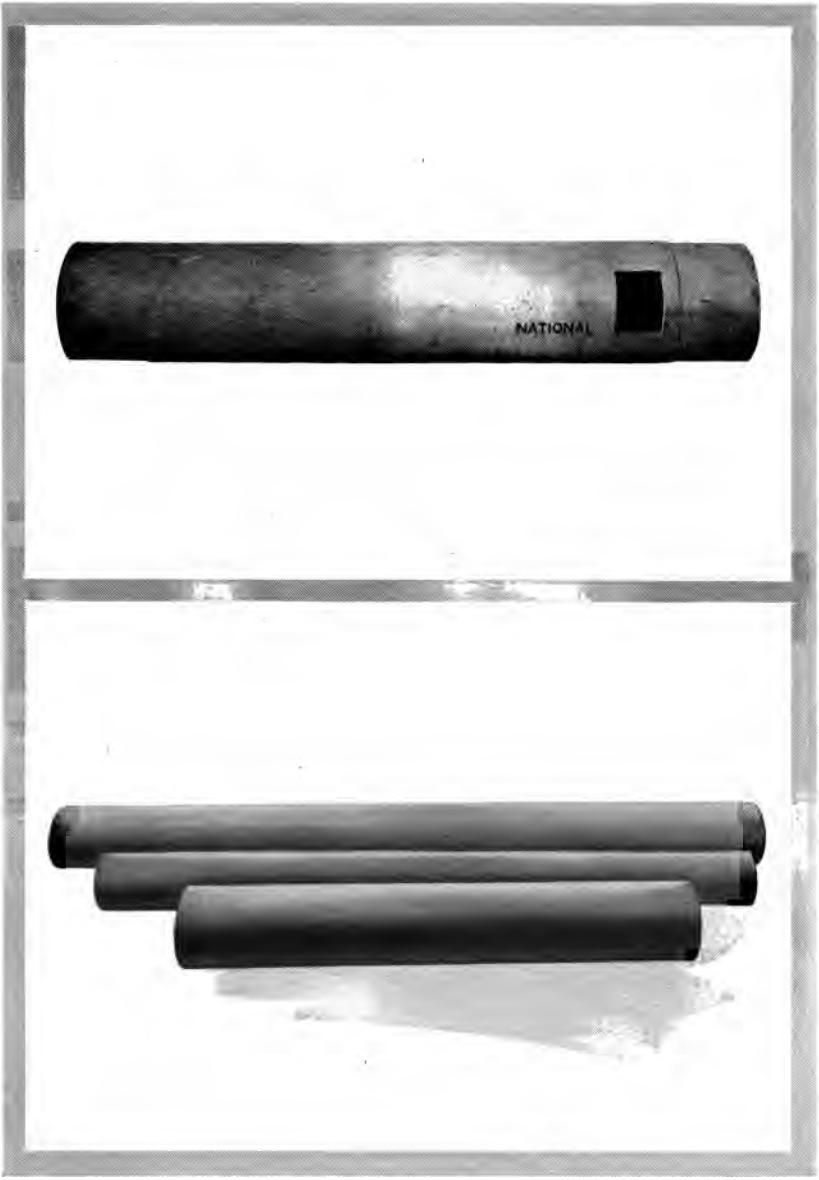
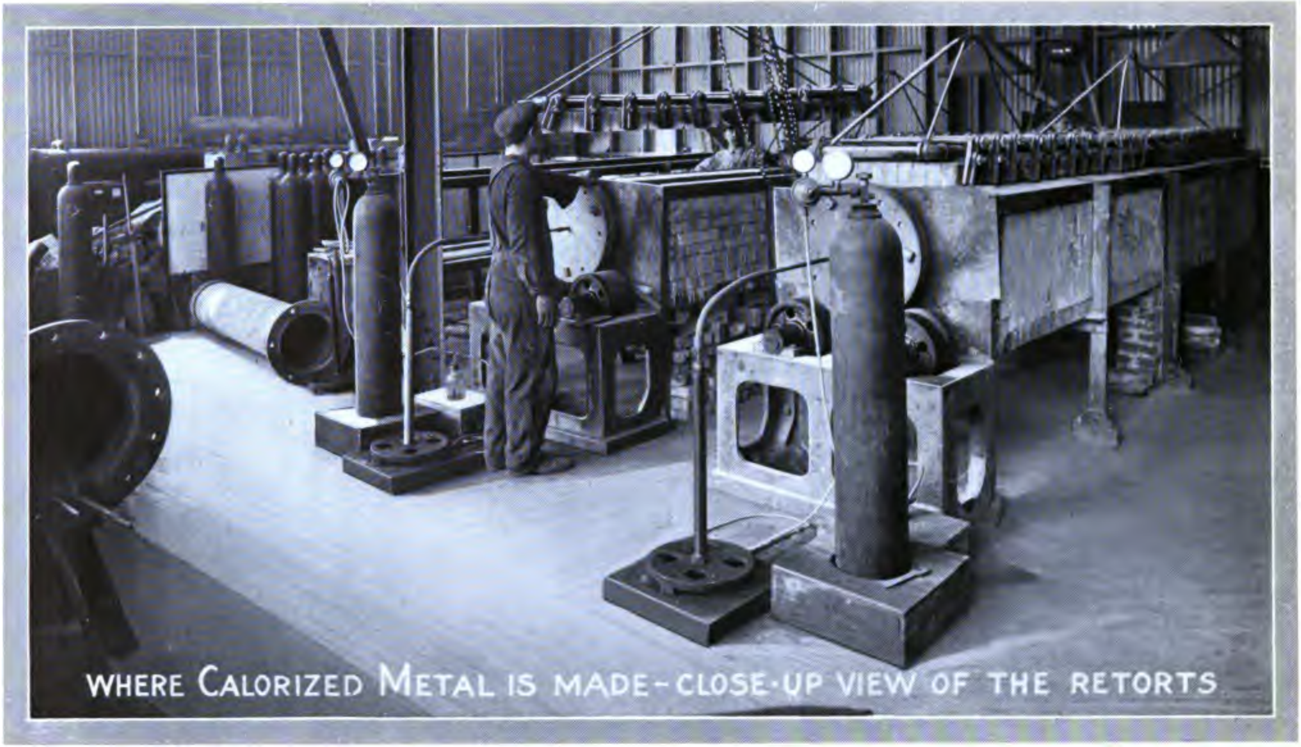


Fig. 18 & 19.—(Upper) Calorized retort for American Gas Furnace Company's special rotating furnace; (Lower) A group of calorized retorts, largest 15ft. long



WHERE CALORIZED METAL IS MADE—CLOSE-UP VIEW OF THE RETORTS

Calorized Internal Combustion Engine Valves and Pistons:

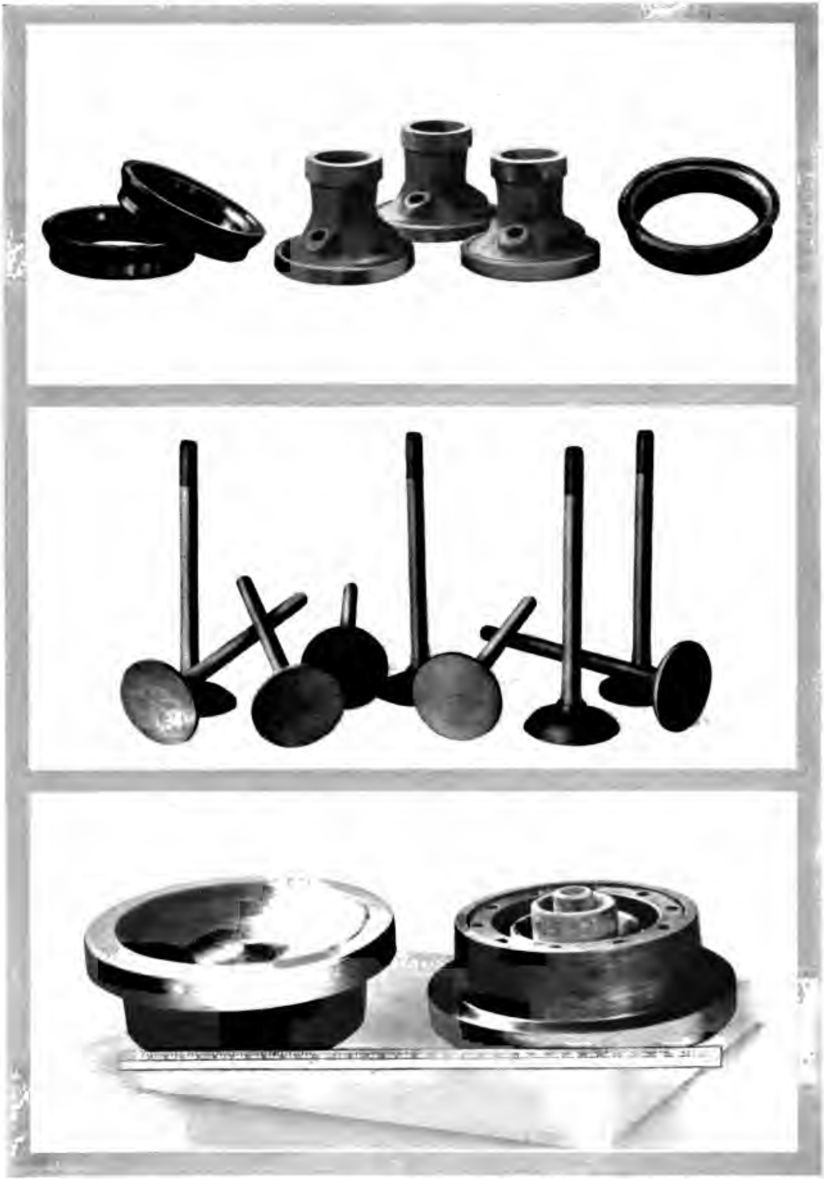
All types of fuel engines, from low compression to Diesel, offer opportunity for the profitable employment of calorized metal. In the low compression type, hot plates and hot bulbs have been successfully calorized. The illustrations in Figs. 20, 21 and 22 show calorized valves, valve seats and pistons.

Furnace Ovens—Kilns and Retorts:

Many furnaces, kilns, ovens and retorts employed in various manufacturing processes were originally made of iron or steel. This metal had a limited heat-resisting quality and was reduced to scrap in a short time. It was repeatedly replaced, but its life was short because of the excessively high temperatures and the same performance continuing indefinitely. As the price of the metals increased, the use of the other materials was considered by engineers in an effort to reduce costs. They built these furnaces from fire-brick and various refractory materials. In a great many instances these materials were used at a loss of 25% to 75% in efficiency, but were adopted because the repair costs on iron and steel were prohibitive. Calorizing can be applied to metal furnace linings, baffle plates, etc., the cost of these calorized plates per unit of service being in a great many cases much less than that of refractory materials. There is an unlimited field for calorizing as applied to equipment of this nature.

Unlimited Future:

There are many possible applications of calorized metal which have not been considered, for the reason that only within the last six months has calorizing been available to the commercial world. The illustrations shown in this article may suggest to the reader further applications of this process. Every industry in which heat-treating processes are employed has certain operations where metal equipment is subjected to high temperatures. Many manufacturers have developed processes of their own, which are not generally known and therefore cannot be described here. It is impossible to enumerate or describe in detail the great number of applications of calorizing. Every plant presents its individual problem, and it is the object of the writer to illustrate several applications with the idea of suggesting to the Engineer, Metallurgist and Plant Manager, possible applications to special equipment used in his particular process of manufacture.



Figs. 20, 21, 22.—(Upper) Special valves and valve seats for Diesel engines; (Center) Gas engine valves; (Lower) 15-in. piston heads for Diesel engines

Heat Treating Equipment:

Perhaps the largest and most easily developed field for calorizing lies in its application to the various pots, boxes, tubes, retorts, and special equipment employed in the many heat treating processes. A large quantity of the above mentioned articles have been successfully calorized, their average life being over eight times that of the uncalorized equipment, resulting in a great saving by the use of calorized equipment.

1. In that one calorized article replaces several uncalorized articles.
2. Where an installation charge is involved it is reduced more than 80%.
3. Costly shut downs due to repairs, etc., are very largely eliminated.
4. Storage, handling, material, labor, clerical work, freight, and time are saved by 75% to 80% or more.

A notable feature is that calorizing can be applied to any of this equipment without necessitating change in its design or construction.

Calorized Wrought vs. Cast Metal:

30% of the metal parts which have been calorized to date are cast iron or cast steel, and these have generally given very excellent results. Cast iron or cast steel, however, is much inferior to calorized wrought metal, owing to three things:

1. Imperfection of castings, that is, the low grade of castings usually used for heat treating receptacles generally contain such common imperfections as blow holes, sand and slag inclusions, etc. These do not present a uniform outer structure to be calorized.
2. The foreign material in such low grade castings causes irregular depth of infusion of the aluminum alloy.
3. Even though the outer surface of a casting may be perfect, its "growth" may be such as to crack the harder calorized portion before it has completed its normal period of service.

A natural conclusion from the above is that calorized castings can only be guaranteed to the extent that the castings themselves can be guaranteed "free from imperfections." The above statement, however, bears no relation to the cost of calorized castings per heat hour as compared to uncalorized castings. In practically every instance the calorized castings have effected considerable saving, lasting as a rule from three to seven times longer than the uncalorized. Wherever possible, however, it is advisable to use wrought or malleable material. The former is free from all the defects of castings, and the latter free from 75% of them, including "growth." Experiments upon calorized sheet metal pots and boxes have been most successful, and there are many points in their favor which would warrant the additional cost over cast metal, even though they be uncalorized. A few of these points are outlined as follows:

1. They are much lighter, thereby eliminating large transportation and handling expense.

2. They are much stronger, eliminating breakage and allowing tight packing with less danger of warping.

3. The capacity of a given size furnace is greatly increased when fitted with wrought steel pots.

4. The bulk metal contained in wrought steel pots is generally less than one-third of that contained in a cast pot of similar inside dimensions. In other words two-thirds of the "dead head" is removed from your furnace charge. This saves much time in firing and a very appreciable amount of fuel.

Wrought steel pots are also very superior for melting metals such as lead, tin and zinc, and for the holding of spelter in dip brazing. By referring to the table of specific heats of metals on page 34, it will be observed that the specific heat of lead is .0314, while that of iron is four times as great, or .1298. In other words it takes as much heat to heat one pound of iron as it does four pounds of lead. The advantage of keeping the pot light is very evident. The specific heat of metals as tin and zinc, which are used in such alloys as stereotype, linotype, and babbitt, is very nearly that of lead, and the advantage of steel pots is relatively as great.

It is quite feasible to make up carbonizing and annealing boxes in any shapes or sizes from sheet steel. These can be riveted or welded together (preferably welded), and offer excellent subjects for calorizing. Seamless drawn steel pots in round shapes are very desirable. These can be procured in sizes from 2⅞″ diameter by 3″ depth to 26″ diameter by 30″ depth, with round or flat bottoms, and with or without flanges; from stock varying from 10 gauge to 1″ in thickness.

Seamless drawn steel pots are shown in Fig. 13, and cast and sheet steel boxes are shown on page 29.

Calorizing As Applied to the Glass Making Industry:

There are many parts of special glass making machinery which are subject to extreme oxidation, and consequently can be greatly benefited by calorizing. Parts of glass melting and pouring equipment, also special moulds, dies, and nozzles of various kinds have been successfully calorized. These may suggest further applications.

Government Use of Calorized Metal:

The United States Government has made several installations of Calorized equipment, and there are large Government Contracts covering Calorized metal now being executed. These include a variety of equipment from gas making retorts to Diesel engine parts, and valves for aviation motors. Experiments on the latter are now being carried on, and if successful will be of unlimited value. In this connection it is interesting to note that the British Thomson Houston Company (the English Branch of the General Electric Company) has done a considerable amount of calorizing for the British Government as applied to engine parts and other apparatus used for war purposes.

Special Experiments:

There have been a limited number of experiments with calorized metal to determine its value in the Chemical Industries. Most of these were conducted to ascertain the action of certain gases, alkalies, acids, etc., upon the calorized metal, and many of them were highly successful. Samples of calorized metal will be gladly furnished for test purposes. Calorizing, however, is primarily designed as a heat-resistant.

Conveying Apparatus:

In the various industries are many applications of calorizing to such articles as conveyor chains and buckets, muffle rolls, conveyor screw shafts, etc., used in "continuous operation" furnaces. Rotary dryers and roasting oven parts may also be benefited by calorizing. Car parts, spouts, and chutes for handling slag, and pouring gates, etc., offer very excellent subjects.

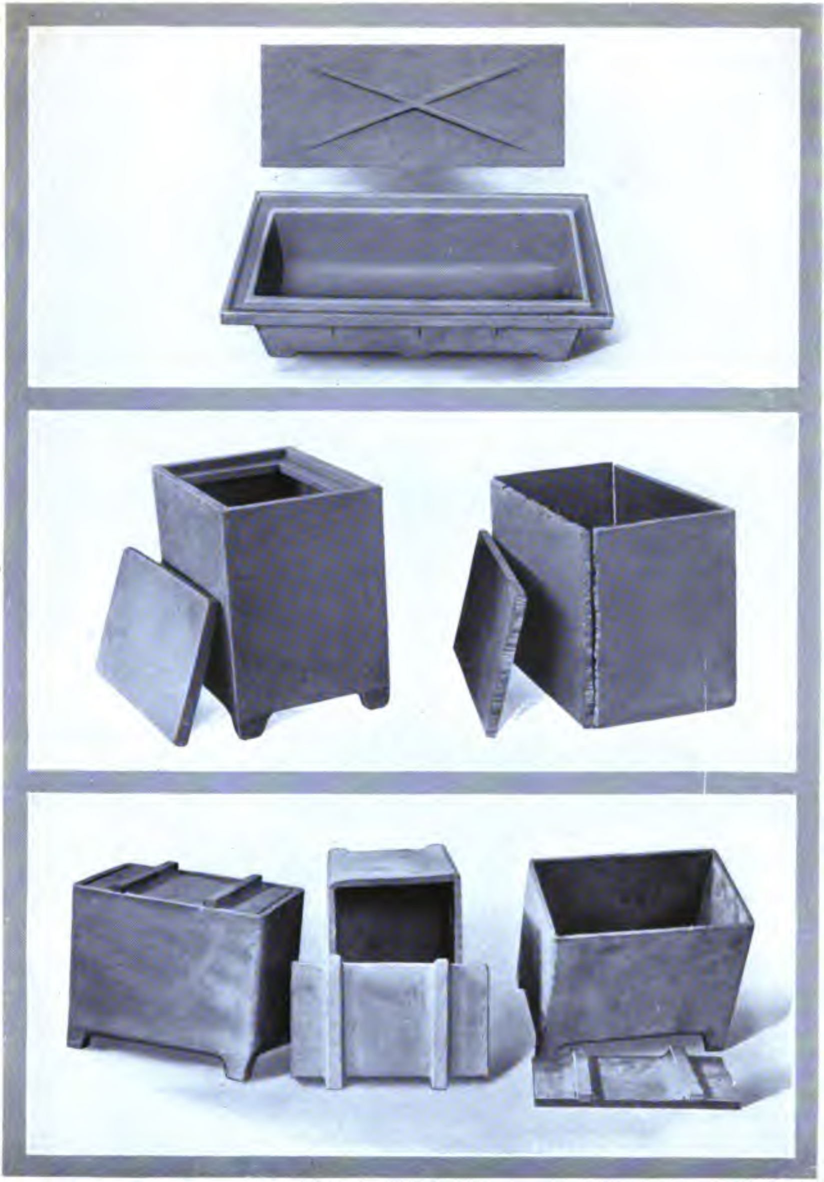


Fig. 23—(Upper) Calorized cast steel annealing box of special design; Fig. 24—(Middle) Left, calorized cast steel carbonizing box. Right, shows construction of a similar box from sheet steel. This is later welded and calorized; Fig. 25 (Lower) Group of calorized steel plate carbonizing boxes

USEFUL TABLES

DEPENDABLE AND UP-TO-DATE

Specific Heats Per Molecular Volumes

Gas	Under Constant Pressure	Under Constant Volume
Perfect Gases (O_2N_2, H_2, CO)	$6.83 \times 10^{-3} + 1.2 \times 10^{-6}t$	$4.83 \times 10^{-3} + 1.2 \times 10^{-6}t$
Water Vapor, H_2O	$8.08 \times 10^{-3} + 5.8 \times 10^{-6}t$	$6.08 \times 10^{-3} + 5.8 \times 10^{-6}t$
Carbon Dioxide, CO_2	$8.52 \times 10^{-3} + 7.4 \times 10^{-6}t$	$6.52 \times 10^{-3} + 7.4 \times 10^{-6}t$
Methane, CH_4	$9.78 \times 10^{-3} + 12. \times 10^{-6}t$	$7.78 \times 10^{-3} + 12. \times 10^{-6}t$

Specific Heats of Gases Per Kilogram

Gases	Under Constant Pressure	Under Constant Volume
Oxygen	$.213 + 38 \times 10^{-6}t$	$.150 + 38 \times 10^{-6}t$
Nitrogen and Carbon Monoxide	$.243 + 42 \times 10^{-6}t$	$.171 + 42 \times 10^{-6}t$
Hydrogen	$3.400 + 600 \times 10^{-6}t$	$2.400 + 600 \times 10^{-6}t$
Water Vapor	$.447 + 324 \times 10^{-6}t$	$.335 + 324 \times 10^{-6}t$
Carbon Dioxide	$.193 + 168 \times 10^{-6}t$	$.150 + 168 \times 10^{-6}t$
Methane	$.608 + 748 \times 10^{-6}t$	$.491 + 748 \times 10^{-6}t$

Weights and Specific Gravities of Gases Found in Furnaces

Gas	Formula	Specific Gravity		Wt. of 1 Lit. at 0 C. 760 mm., 45 Latitude and at Sea Level
		Hydrogen = 2, Mol Weight	Air = 1.000	
Acetylene	C_2H_2	25.947	.89820	1.16143 Grms.
Atmospheric Air	....	......	1.00000	1.293052 “
Ethane	C_2H_6	29.947	1.03667	1.34047 “
Ethylene	C_2H_4	27.947	0.96744	1.25095 “
Carbon Monoxide	CO	27.937	0.96709	1.25050 “
Carbon Dioxide	CO_2	43.900	1.51968	1.96503 “
Hydrogen	H_2	2.000	0.069234	0.089523 “
Hydrogen Sulphide	H_2S	34.000	1.17697	1.52189 “
Methane	CH_4	15.974	0.55297	0.71502 “
Nitrogen	N_2	28.024	0.97010	1.25440 “
Oxygen	O_2	31.927	1.1052	1.42908 “
Sulphur Dioxide	SO_2	63.927	2.21295	2.86146 “
Water Vapor	H_2O	17.963	0.62182	0.80405 “
Ammonia	NH_3	17.012	0.5889	0.7615 “

Table Showing Weight in Pounds

of

Sheets and Bar Aluminum; also Brass and Steel

Water at 62° =62.355 lbs.

Specific Gravity of Rolled Aluminum, 2.68. Specific Gravity of Rolled Brass, 8.549

Specific Gravity of Rolled Steel, 7.858.

Aluminum taken as 1, Brass is 3.190 times heavier, Steel is 2.9322 times heavier.

Thickness or Diameter in inches		Sheet per Square Foot			Square Bars One Foot Long			Round Bars One Foot Long		
Fraction	Decimal	Aluminum	Brass	Steel	Aluminum	Brass	Steel	Aluminum	Brass	Steel
1/16	.0625	.869	2.77	2.55	.004	.014	.013	.003	.011	.010
1/8	.125	1.739	5.55	5.10	.018	.057	.053	.014	.045	.042
3/16	.1875	2.609	8.32	7.65	.041	.131	.119	.032	.102	.094
1/4	.2500	3.479	11.10	10.20	.072	.230	.212	.057	.182	.167
5/16	.3125	4.348	13.87	12.75	.114	.361	.333	.089	.284	.261
3/8	.3750	5.218	16.64	15.30	.163	.520	.478	.128	.408	.375
7/16	.4375	6.088	19.42	17.85	.222	.708	.651	.174	.555	.511
1/2	.5000	6.958	22.20	20.40	.290	.925	.850	.227	.724	.667
9/16	.5625	7.827	24.97	22.95	.367	1.171	1.076	.288	.919	.845
5/8	.6250	8.697	27.74	25.50	.453	1.445	1.328	.356	1.136	1.043
11/16	.6875	9.567	30.52	28.05	.548	1.748	1.608	.430	1.372	1.262
3/4	.7500	10.436	33.29	30.60	.652	2.080	1.913	.513	1.646	1.502
13/16	.8125	11.306	36.07	33.15	.766	2.445	2.245	601	1.917	1.763
7/8	.8750	12.175	38.84	35.70	.888	2.833	2.603	.697	2.223	2.044
15/16	.9375	13.045	41.61	38.25	1.019	3.251	2.989	.800	2.552	2.347
1	1.0000	13.915	44.39	40.80	1.159	3.697	3,400	.911	2.906	2,670
1 1/16	1.0625	14.784	47.16	43.35	1.309	4.176	3.838	1.028	3.279	3.014
1 1/8	1.125	15.654	49.94	45.90	1.467	4.680	4.303	1.152	3.675	3.379
1 3/16	1.1875	16.524	52.71	48.45	1.635	5.216	4.795	1.284	4.096	3.766
1 1/4	1.2500	17.394	55.48	51.00	1.812	5.780	5.312	1.423	4.539	4.173
1 5/16	1.3125	18.263	58.26	53.55	1.997	6.370	5.857	1.569	5.003	4.600
1 3/8	1.3750	19.133	61.04	56.10	2.192	6.992	6.428	1.722	5.491	5.049
1 7/16	1.4375	20.002	63.81	58.65	2.396	7.644	7,026	1.882	6.002	5.518
1 1/2	1.5000	20.872	66.58	61.20	2.609	8.322	7.650	2.049	6.536	6.008
1 9/16	1.5625	21.741	69.35	63.75	2.831	9.030	8.301	2.223	7.091	6.520
1 5/8	1.6250	22.611	72.13	66.30	3.062	9.768	8.978	2.405	7.672	7.051
1 11/16	1.6875	23.481	74.90	68.85	3.302	10.53	9.682	2.593	8.271	7.604
1 3/4	1.7500	24.351	77.67	71.40	3.550	11.32	10.41	2.789	8.896	8.178
1 13/16	1.8125	25.250	80.54	73.95	3.810	12.15	11.17	2.992	9.544	8.773
1 7/8	1.8750	26.090	83.22	76.50	4.075	13.00	11.95	3.202	10.21	9.388
1 15/16	1.9375	26.960	86.00	79.05	4.352	13.88	12.76	3.417	10.90	10.02
2	2.0000	27.829	88.77	81.60	4.638	14.79	13.60	3.642	11.62	10.68

Table of Specific Gravity and Unit Weights

	Specific Gravity	Authcrity	Lbs. per Cu. Ft.	Lbs. per Cu. In.
Aluminum, pure, cast	2.56		159.63	.0924
" " rolled	2.68		167.11	.0967
" " annealed	2.66		165.86	.0960
" Bronze 10%	7.70	Richie	480.13	.2779
" " 5%	8.26	"	515.63	.2984
Antimony	6.71	R–A	418.86	.2424
Arsenic	5.67	R–A	353.95	.2048
Asphalt (Paving)	1.1–1.6		68–100	.04–.06
Barium	3.75	R–A	234.09	.1355
Zirconium	6.4		400	.231
Bismuth	9.80	R–A	611.76	.3540
Boron	2.45		153.2	.0885
Brass, Cu. 67, Zn. 33, cast	8.32	Haswell	519.36	.3006
" Cu. 60, Zn. 40, cast	8.405	Thurston	524.68	.3036
Brass, plates, high yellow	8.549		533.69	.3088
Brick, Hard	1.5		93	.054
" Soft	2.4		150.	.087
Bronze composition, Cu. 90, Tin, 10	8.669	Thurston	541.17	.3132
Bronze composition, Cu. 84, Tin 16	8.832	Haswell	551.34	.3191
Gun Bronze	8.750	Haswell	546.22	.3161
Tobin Bronze	8.379	A. C. Co.	523.06	.3021
Cadmium	8.60	R–A	536.85	.3107
Calcium	1.57	R–A	98.01	.0567
Caesium	1.88	R–A	117.36	.0679
Cerium	6.68	R–A	417.00	.2413
Chromium	6.8	R–A	425.	.2457
Cinnabar	8.809	Haswell	550.52	.3130
Clay	1.8–2.6		112–162	.065-.094
Coal	1.5		94.	.054
Cobalt	8.50	R–A	530.61	.3071
Concrete	2.0		125.	.072
Copper, pure	8.82	R–A	550.59	.3186
" plates and sheet	8.93	A. of C. M.	558.	.3222
Cypress	.41–.66		25–41	.015-.024
Gasoline	.737		45.96	.02661
Gold	19.32	R–A	1206.05	.6979
Granite	2.7		168.4	.0975
Graphite	2.26		141.	.0816
Indium	7.42	R–A	463.19	.2681
Iridium	22.42	R–A	1399.57	.8099
Iron cast	7.218	Kent	450.08	.2605
" wrought	7.70	"	480.13	.2779
" Wire	7.774	Haswell	485.29	.2808
Iron, pure	7.86	R–A	490.66	.2840
Lead	11.37	R-A	709.77	.4108
Limestone	2.7		168.4	.0975
Lithium	0.57	R–A	35.6	.0206

Table of Specific Gravity and Unit Weights

(Continued)

	Specific Gravity	Authority	Lbs. per Cu. Ft.	Lbs. per Cu. In.
Magnesium	1.74	R–A	108.62	.0629
Manganese	7.39		461.	.2669
Maple (wood)	.53–1.05		33–65	.02–.04
Mercury	14.2		887.	.319
Molybdenum	8.60	R–A	536.85	.3107
Mortar	1.60		100.	.0578
Nickel	8.80	R–A	549.34	.3179
Osmium	22.48	R–A	1403.31	.8121
Palladium	11.50	R–A	719.	.4154
Petroleum	.8		50.	.029
Platinum	21.50	R–A	1342.13	.7767
Porcelain	2.4		150.	.087
Potassium	0.87	R–A	54.31	.0314
Rhodium	12.10	R–A	755.34	.4371
Rubber	.933		58.19	.0337
Ruthenium	12.26	R–A	765.33	.4429
Selenium	4.50	Haswell	280.91	.1626
Silver	10.53	R–A	657.33	.3805
Sodium	0.97	R–A	60.55	.0350
Steel, Bessemer	7.852	Haswell	489.00	.2834
“ soft	7.854	Kent	489.74	.2838
Strontium	2.54	R–A	158.56	.0918
Sulphur	2.		125.	.072
Tantalum	16.6		1039.	.600
Tar	1.015		63.3	.0366
Thallium	11.85	R–A	739.73	.4281
Thorium	11.10	R–A	692.93	.4010
Tin, pure	7.29	R–A	455.08	.2634
Titanium	45		281.	.1626
Tungsten	19.10	R–A	1192.31	.6900
Uranium	18.70	R–A	1167.45	.6755
Vanadium	5.50	R–A	343.34	.1987
Zinc, cast	6.867	Haswell	428.30	.2479
“ pure	7.15	R–A	446.43	.2583
“ rolled	7.191	Haswell	448.90	.2598

Authorities:

R–A	Sir Roberts-Austen.
Haswell	Haswell's Engineer's Pocket Book.
Kent	Kent's Mechanical Engineer's Pocket Book.
Thurston	Report of Committee on Metallic Alloys of U. S. Board appointed to test iron, steel, and other metals. Thurston's Materials of Engineering.
Riche	Quoted by Thurston.
A. C. Co.	Ansonia Brass & Copper Co.
A. of C. M.	Association of Copper Manufacturers.

Table of Specific Heats of Metals

	Specific* Heat	Authority
Wrought iron	.1138	Regnault
“ “ 32–212 F	.1098	Dulong & Petit
“ “ 32–392 F	.1150	“ “
“ “ 32–572 F	.1218	“ “
“ “ 32–662 F	.1255	“ “
Cast iron	.1298	Regnault
Steel, soft	.1165	“
“ tempered	.1175	“
Copper	.09515	“
“ 32–212 F	.0927	Dulong & Petit
“ 32–572 F	.1013	“ “
Cobalt	.10696	Regnault
“ carburetted	.11714	“
Nickel	.1086	“
“ carburetted	.1119	“
Tin, English	.05695	“
“ Indian	.05623	“
Zinc	.09555	“
“ 32–212 F	.0927	Dulong & Petit
“ 32–572 F	.1015	“ “
Brass	.0939	Regnault
Lead	.0314	“
Platinum, sheet	.03243	“
“ 32–212 F	.0335	Dulong & Petit
“ at 572 F	.03434	Pouillet
“ “ 932 F	.03518	“
“ “ 1832 F	.03718	“
“ “ 2995 F	.03818	“
Mercury, solid	.0319	Regnault
“ liquid	.03332	“
“ 32–212 F	.033	Dulong & Petit
“ 32–572 F	.035	“ “
Antimony	.05077	Regnault
“ 32–572 F	.0547	Dulong & Petit
Bismuth	.03084	Regnault
Gold	.03244	“
Silver	.05701	“
“ 32–572 F	.611	Dulong & Petit
Manganese	.14411	Regnault
Iridium, 32–212 F	.0323	“
Tungsten	.03636	“

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*The specific heat of a substance is the ratio between its thermal capacity and that of water; hence its numerical value is equal to the ratio of the heat received by the body to the change of temperature produced.

Weight of Aluminum, Wrought Iron, Steel, Copper and Brass Plates

Thickness Determined by American (Brown & Sharpe) Gauge.

Water at 62° Fahrenheit, 62.355 lbs. per cubic foot.

Rolled	Wrought Iron	is 2.8724 times heavier than rolled Aluminum.
"	Steel	" 2.9322 " " " " "
"	Copper	" 3.3321 " " " " "
"	Brass	" 3.1900 " " " " "

	Aluminum	Wrt. Iron	Steel	Copper	Brass
Specific Gravity Rolled Metal	2.680	7.698	7.858	8.930	8.549
Weight per cu. ft. Rolled Metal	167.111	480.000	490.000	556.830	533.073

No. of Gauge	Size of each No.	Weight of Plates per Square Foot.				
		Alum.	Wr't Iron	Steel	Copper	Brass
	Inch	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
0000	.46000	6.406	18.400	18.784	21.345	20.435
000	.40964	5.704	16.386	16.728	19.010	18.200
00	.36480	5.080	14.592	14.895	14.928	16.205
0	.32486	4.524	12.995	13.265	15.075	14.431
1	.28930	4.029	11.572	11.813	13.425	12.851
2	.25763	3.588	10.306	10.520	11.955	11.445
3	.22942	3.195	9.173	9.369	10.647	10.193
4	.20431	2.845	8.173	8.343	9.481	9.076
5	.18194	2.534	7.278	7.430	8.443	8.083
6	.16202	2.256	6.481	6.616	7.513	7.197
7	.14428	2.009	5.770	5.890	6.693	6.408
8	.12849	1.789	5.139	5.246	5.961	5.707
9	.11443	1.594	4.578	4.673	5.311	5.084
10	.10189	1.418	4.075	4.160	4.728	4.526
11	.090742	1.264	3.630	3.706	4.212	4.032
12	.080808	1.126	3.234	3.301	3.751	3.591
13	.071961	1.002	2.878	2.938	3.339	3.196
14	.064084	.8924	2.564	2.617	2.974	2.847
15	.057068	.7946	2.282	2.330	2.648	2.535
16	.050820	.7078	2.033	2.075	2.358	2.258
17	.045257	.6302	1.810	1.848	2.100	2.010
18	.040303	.5612	1.612	1.646	1.870	1.790
19	.035890	.4998	1.436	1.465	1.665	1.594
20	.031961	.4450	1.278	1.305	1.483	1.420
21	.028462	.3964	1.139	1.162	1.321	1.265
22	.025347	.3530	1.014	1.035	1.176	1.126
23	.022571	.3143	.9028	.9216	1.047	1.003
24	.020100	.2798	.8039	.8207	.9325	.8927
25	.017900	.2492	.7159	.7308	.8304	.7949
26	.015940	.2219	.6375	.6508	.7395	.7080
27	.014195	.1976	.5678	.5796	.6587	.6305
28	.012641	.1760	.5066	.5161	.5865	.5514
29	.011257	.1567	.4503	.4597	.5224	.5001
30	.010025	.1396	.4011	.4095	.4653	.4455
31	.008928	.1244	.3572	.3647	.4144	.3967
32	.007950	.1107	.3181	.3247	.3690	.3532
33	.007080	.09854	.2831	.2890	.3287	.3147
34	.006304	.08778	.2522	.2569	.2925	.2801
35	.005614	.07817	.2246	.2292	.2605	.2494
36	.005000	.06962	.2000	.2042	.2320	.2221

Melting Points of Various Substances

In order of melting points.
The following figures have been taken from various authorities.
Those marked (*) are given by Sir-Roberts-Austen.

Substance	Deg. Cent.	Deg. Fahr.
Sulphurous Acid	—72.7	— 99
Carbonic Acid	—78.2	—109
Mercury	—38.7	—37.7
Bromine	—7.3	18.9
Turpentine	—10	14
Ice	0.0	32
Nitroglycerine	7.2	45
Tallow	—45	92—113
Phosphorous	44.1	112—113
Acetic Acid	17.5	63.5
Stearine	42.8—48.9	109—120
Spermaceti	48.9	120
Margaric Acid	55.0—60.0	131—140
Potassium	62.3	144.5
Wax	40—67	104—154
Stearic Acid	70.0	158
Sodium	97.5	207.6
Alloy { **3 lead** **2 tin** **5 bismuth**	100	212
Iodine	113.0—115.0	235.4—239
Sulphur	115	239
Alloy, 1½ tin, 1 lead	186	367
Alloy, 1 tin, 1 lead	215	419
Tin	231.9	449
Bismuth	271	520
Cadium	320.9	610
Lead	327.4	621.3
Zinc	394	741
Antimony	630	1166
Magnesium	651.0	1204
Aluminum	658.7	1218
Calcium	810	1490
Bronze. 10% Pb., 80% Cu., 10% Sn.	945	1733
Silver	960.5	1760.9
Gold	1063	1945
Potassium Sulphate	1066	1951
Copper	1083.0	1981
Cast Iron—White	1050 —1135*	1922 —2075*
Cast Iron—Gray	1220*—1530	2228*—2786
Manganese	1260	2300
Steel	1300 —1388	2372 —2532
Steel—hard	1410*	2570*
Silicon	1420	2588
Nickel	1452	2646
Steel—mild	1475*	2687*
Cobalt	1478	2692
Chromium	1520	2768
Wrought Iron	1500 —1530	2732 —2786
Palladium	1549	2820
Vanadium	1720	3128
Platinum	1755	3192
Titanium	1795	3263
Tantalum	2850	5162
Tungsten	3270	5918

The melting point of metals varies in the tables given by standard authorities due to the amount of impurities contained in the samples experimented upon, and also due to the slight inaccuracy of the instruments or methods used in determining high temperatures, as well as to errors in observation.

Linear Expansion

Co-efficients of Linear Expansion

Authority, Sir Roberts-Austen

	Cent.	**Fahr.**
Potassium	.0000841	**.0000476**
Sodium	.0000710	**.0000395**
Indium	.0000417	**.0000231**
Cadmium	.0000306	**.0000170**
Thallium	.0000302	**.0000168**
Lead	.0000292	**.0000162**
Zinc	.0000291	**.0000161**
Magnesium	.0000269	**.0000150**
Aluminum	.0000231	**.0000130**
Tin	.0000223	**.0000124**
Silver	.0000192	**.0000107**
Tellurium	.0000167	**.0000093**
Copper	.0000167	**.0000093**
Bismuth	.0000162	**.0000090**
Gold	.0000144	**.0000080**
Nickel	.0000127	**.0000071**
Cobalt	.0000123	**.0000070**
Iron	.0000121	**.0000069**
Palladium	.0000117	**.0000065**
Antimony	.0000105	**.0000058**
Ruthenium	.0000096	**.0000053**
Platinum	.0000089	**.0000050**
Rhodium	.0000085	**.0000046**
Iridium	.0000070	**.0000039**
Osmium	.0000065	**.0000036**
Arsenic	.0000055	**.0000031**

Conversion Tables
of
Fahrenheit and Centigrade Scales

Cent.	Fahr.	Cent.	Fahr.	Fahr.	Fahr.
0	32	260	500	520	968
5	41	265	509	525	977
10	50	270	518	535	986
15	59	275	527	535	995
20	68	280	536	540	1004
25	77	285	545	545	1013
30	86	290	554	550	1022
35	95	295	563	555	1031
40	104	300	572	560	1040
45	113	305	581	565	1049
50	122	310	590	570	1058
55	131	315	599	575	1067
60	140	320	608	580	1076
65	149	325	617	585	1085
70	158	330	626	590	1094
75	167	335	635	595	1103
80	176	340	644	600	1112
85	185	345	653	605	1121
90	194	350	662	610	1130
95	203	355	671	615	1139
100	212	360	680	620	1148
105	221	365	589	625	1157
110	230	370	698	630	1166
115	239	375	707	635	1175
120	248	380	716	640	1184
125	257	385	725	645	1193
130	266	390	734	650	1202
135	275	395	743	655	1211
140	284	400	752	660	1220
145	293	405	761	665	1229
150	302	410	770	670	1238
155	311	415	779	675	1247
160	320	420	788	680	1256
165	329	425	797	685	1265
170	338	430	806	690	1274
175	347	435	815	695	1283
180	356	440	824	700	1292
185	365	445	833	705	1301
190	374	450	842	710	1310
195	383	455	851	715	1319
200	392	460	860	720	1328
205	401	465	869	725	1337
210	410	470	878	730	1346
215	419	475	887	735	1355
220	428	480	896	740	1364
225	437	485	905	745	1373
230	446	490	914	750	1382
235	455	495	923	755	1391
240	464	500	932	760	1400
245	473	505	941	765	1409
250	482	510	950	770	1418
255	491	515	959	775	1427

Conversion Tables of Fahrenheit and Centigrade Scales

(*Continued*)

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
780	1436	1060	1940	1340	2444
785	1445	1065	1949	1345	2453
790	1454	1070	1958	1350	2462
795	1463	1075	1967	1355	2471
800	1472	1080	1976	1360	2480
805	1481	1085	1985	1365	2489
810	1490	1090	1994	1370	2498
815	1499	1095	2003	1375	2507
820	1508	1100	2012	1380	2516
825	1517	1105	2021	1385	2525
830	1526	1110	2030	1390	2534
835	1535	1115	2039	1395	2543
840	1544	1120	2048	1400	2552
845	1553	1125	2057	1405	2561
850	1562	1130	2066	1410	2570
855	1571	1135	2075	1415	2579
860	1580	1140	2084	1420	2588
865	1589	1145	2093	1425	2597
870	1598	1150	2102	1430	2606
875	1607	1155	2111	1435	2615
880	1616	1160	2120	1440	2624
885	1625	1165	2129	1445	2633
890	1634	1170	2138	1450	2642
895	1643	1175	2147	1455	2651
900	1652	1180	2156	1460	2660
905	1661	1185	2165	1465	2669
910	1670	1190	2174	1470	2678
915	1679	1195	2183	1475	2687
920	1688	1200	2192	1480	2696
925	1697	1205	2201	1485	2705
930	1706	1210	2210	1490	2714
935	1715	1215	2219	1495	2723
940	1724	1220	2228	1500	2732
945	1733	1225	2237	1505	2741
950	1742	1230	2246	1510	2750
955	1751	1235	2255	1515	2759
960	1760	1240	2264	1520	2768
965	1769	1245	2273	1525	2777
970	1778	1250	2282	1530	2786
975	1787	1255	2291	1535	2795
980	1796	1260	2300	1540	2804
985	1805	1265	2309	1545	2813
990	1814	1270	2318	1550	2822
995	1823	1275	2327	1555	2831
1000	1832	1280	2336	1560	2840
1005	1841	1285	2345	1565	2849
1010	1850	1290	2354	1570	2858
1015	1859	1295	2363	1575	2867
1020	1868	1300	2372	1580	2876
1025	1877	1305	2381	1585	2885
1030	1886	1310	2390	1590	2894
1035	1895	1315	2399	1595	2903
1040	1904	1320	2408	1600	2912
1045	1913	1325	2417		
1050	1922	1330	2426		
1055	1931	1335	2435		